# Design of an Integrated Assessment of Re-distributed Manufacturing for the Sustainable, Resilient City

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**Abstract.** Re-distributed manufacturing (RDM) has the potential to be beneficial to business and society through creating jobs, reducing the environmental impacts of production, and improving organizational and societal resilience to future disturbances. The potential impacts of RDM for a city-region are complex and their exploration requires the consideration of a wide range of issues – societal, technical, logistical, and environmental. This paper discusses the use of an approach called Integrated Assessment to carry out an initial scoping of the issues. A research framework for RDM, and the key themes from a workshop that explored the causal relationships between different types of resilience, sustainability, and the manufacturing sectors are presented.

**Keywords:** Systems thinking, sustainable manufacturing and society, re-distributed manufacturing, manufacturing resilience.

## 1 Introduction

The research project *Redistributed Manufacturing for a Resilient, Sustainable City* (RDM|RSC) is studying the impact of moves towards smaller-scale and local manufacturing with a focus on the resilience and sustainability of a city – Bristol, UK – and its region. One definition of Re-distributed Manufacturing (RDM) is: '*Technology, systems and strategies that change the economics and organisation of manufacturing, particularly with regard to location and scale*' [1].

The project's own working definition of RDM is: "Redistributed manufacturing is the **localization** of the design and production of manufactured artefacts, especially through the use of **small-scale** and innovative production methods and associated business models, which has the potential to benefit a region's **economy, society and environment**, and to improve its **resilience** to future megatrends such as climate change and globalization of supply networks". Under the umbrella of RDM could arise: new business models, new manufacturing technologies, new skills, and the use of new materials. RDM could also involve bringing back traditional making skills and use of traditional materials, but in a new way.

This paper presents an initial scoping of the societal level issues and potential impact associated with RDM, in relation to the resilience and sustainability of a region.

### 1.1 Definition of Terms

For this project we take "manufacturing" to be the creation (or repair, or remanufacture) of tangible artefacts from raw materials and/or parts, but not including the following: construction of infrastructure, utilities, design (when not connected with manufacturing), software, mining and minerals, and agriculture. We take the term "disturbances" to include short-term shocks (e.g. lasting from a few hours to a few weeks) and long-term stressors (which build up over months or years), both of which can affect a city-region and its manufacturing sectors. Disturbances can come from within the region (e.g. social unrest, industrial accidents) or from outside the region at national, EU or global levels (e.g. climate change, global recession, resource scarcity or price rises).

There are many terms that are used in relation to the broad concept of "resilience", including "vulnerability", "adaptive capacity", "robustness", "anti-fragility" [2] – all of which are '*different manifestations of more general processes of response to changes in the relationship between open dynamical systems and their external environment*' [3]. The term "sustainable" as applied to urban areas has also been assigned many interpretations by different authors, including: low $CO_2e$ emissions, low waste generation, management of natural systems to ensure their long-term health, good air quality, and good quality of life for citizens that includes access to jobs, housing, etc.

For this project, we have defined two types of sustainability and two types of resilience, which were formulated to reflect these issues in relation to a city-region and its manufacturing sectors.

**Economic Sustainability**– Local taxes and grants from central government are sufficient to maintain a good quality of civic life, infrastructure, and to support businesses; citizens can be economically self-reliant; businesses can attract investment.

**Environmental Sustainability** – The regional natural environment is viable in the long-term and able to provide natural services such as drainage, manageable water courses, productive soil, healthy forests, good air quality, low levels of toxins, etc.

**Short-term Resilience** - Public and private agencies are able to establish normal services and economic activity soon after short-term economic, social, political, or environmental shocks that disturb public services and/or supply networks.

**Long-term Resilience** – The regional manufacturing sector, economy, and society as a whole is able to evolve and adapt in response to a range of long-term stressors. This evolution will likely look like *'constant change rather than stability'* [4].

In theory, there are many potential beneficial links between RDM and the sustainability and resilience characteristics of a region. These include improving the **productivity** of local manufacturing both in terms of labor and materials; reducing the **environmental impacts** of manufacturing; allowing the use of new **materials** or existing materials to be used in a new way – which could reduce dependence on global supply networks; providing **new jobs** for lower-skilled workers, improving social equity and social resilience; improving the **supply resilience** of a region through producing more locally; reducing the **lifecycle environmental impact** associated with consumption of goods and services in a region; and improving the overall **economic sustainability** of a region through increased diversity and innovation.

To explore these hypotheses, RDM must be viewed through at least two lenses: (i) the impact of the sustainability and resilience of the city-region, and of short and long-term disturbances, on the manufacturing sector; and (ii) the impact of the manufacturing sector on the resilience and sustainability of the city-region, especially in the face of disturbances. This is because RDM could be part of a solution to improving a city-region's resilience in general (i.e. the left view), but at the same time, the viability of manufacturing sectors and the growth of RDM will partly depend on the health of the local city-region (the right view).

## 2 Research Objectives and Methodology

One of the RDM|RSC project objectives is to contribute to the long-term research agenda for RDM, which includes carrying out a high-level scoping of the issue of RDM within a region. This paper is focused on the exploration of the effects of disturbances, past and future, on the city-region and its manufacturing sectors, and the need of the project team to develop an effective, comprehensive, and systemic approach to the task of scoping this issue within the project timeline.

Much research is being done on the resilience of urban areas, including: socio-technical resilience to climate impacts, social and ecological resilience, city resilience, economic resilience of regions [4], and industrial resilience. Bristol has a Strategic Resilience Officer and is one of the Rockefeller Foundation's 100 Resilient Cities (www.100resilientcities.org), but the subject of manufacturing has not yet been strongly included in its resilience work. Similarly, there has been a great deal of research on the concept of a sustainable city, including: the "sustainable city" as an oxymoron [5], sustainable development and carbon control in urban redevelopment [6], and the urban politics of climate change [7]. Papers on sustainability appear to be more likely to question the feasibility of the proposition when compared to those on resilience, possibly due to the fact that the idea of resilience aligns more with standard practices of business continuity planning and risk management.

Since the scale of the project brief is at the regional and societal level, there is a need to consider a wide range of technical and social issues in relation to each other. One established approach to research at the societal level is Integrated Assessment (IA), which has been used to carry out comprehensive assessments of, amongst many other subjects, the impact of climate change on urban areas [8]. IA has been described as '*the interdisciplinary process of integrating knowledge from various disciplines and stakeholder groups in order to evaluate a problem situation from different perspectives and provide support for its solution*' [9]. It takes a comprehensive, systemic approach which includes '*the needs and concerns of communities and industries, as well as the environment*' [10]. For example, the IA approach enables urban planning researchers to '*re-frame the questions that are asked so as to link global, regional and local scales and their interactions in the context of future urban planning*' [8]. Whilst a full IA is out of the scope of the RDM|RSC project, the principles of IA can be used to bring structure to what could be a rather unwieldly research agenda. This structure can inform and contextualize the design of any case studies and help to relate case study results to the overarching research agenda.

The next section describes the application of the principles of an 11-step process for carrying out an IA, as defined in [10], in the RDM|RSC project. The IA steps are quoted in bold italics, along with the work done to address them.

## 3 Integrated Assessment Steps

**Step One:** ***'Clearly identify the aims and objectives of the integrated assessment, including stakeholders and potential audiences for the results and any other products of the IA'*** [10].

The study **purpose** is to address the following research questions: (i) What could be the benefits of developing a systemic and dynamical understanding of relationships between a city's resilience and sustainability, and its manufacturing sectors?; (ii) For whom would these benefits be developed?; (iii) What metrics would be most useful to stakeholders in terms of informing their decision making?; (iv) How could an understanding of dynamical relationships be helpful for the RDM agenda and sustainable manufacturing in general?; (v) What qualitative and/or quantitative methods could deliver such an analysis within a reasonable time frame?

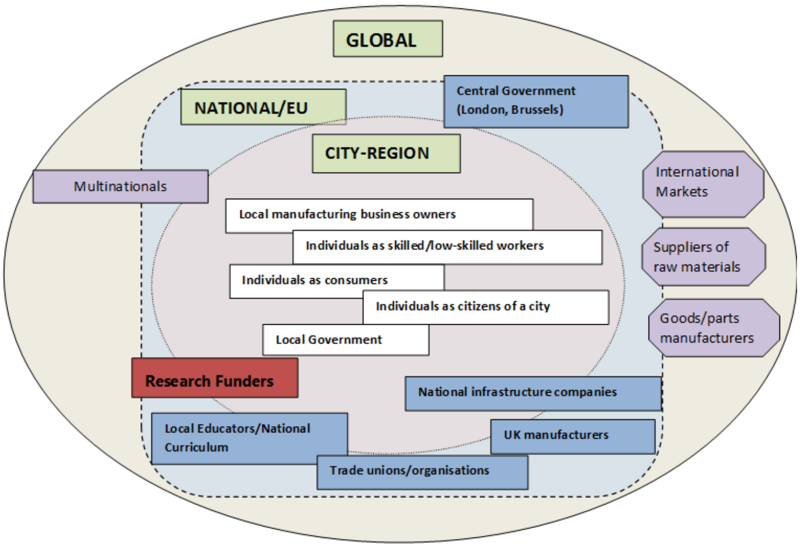


**Fig. 1.** RDM|RSC Research Stakeholder Map, with stakeholder groups (or roles) positioned according to their activities within the city-region, national/EU, and global realms

The **aim** for the IA is to meet this purpose in a way that is comprehensive and theoretically well-founded.

The main **audiences** are: the funding body (the EPSRC[1]), local government (e.g. Bristol City Council), and businesses in the Bristol area. Other potential audiences include: other cities, UK central government policy makers, the sustainable manufacturing community, the research community working on resilience, and those who might gain work in manufacturing. Fig. 1 presents a stakeholder map for the research and where stakeholder activities are carried out in relation to the city-region, national/EU and global spheres.

**Step Two:** ***'Build an understanding of the constraints and issues in the case study as well as possible targets and measures of system performance'*** [10].

The key practical constraint is the limited project timeline and budget coupled with the need to consider a very wide ranging subject that is highly complex. The key developmental constraint is the unavailability of data on regional manufacturing activities.

A STEEPLE (Social, Technical, Economic, Environmental, Political, Legal, and Ethical) analysis of key system elements, including measures of system performance, and short and long-term disturbances, was developed by the project team. The STEEPLE development was based on the team's knowledge, network meetings, local and national risk registers, discussions with experts, and a review of literature.

**Key system elements** include: workforce skills and education, levels of unemployment and inequality, automation, manufacturing technologies/machinery, demand for goods, costs of materials/ parts/energy, number of start-ups, waste generation, emissions (e.g. $CO_2$, NOx, SOx), rules on international trade, UK Government support for innovation, environmental laws, employee legislation, labor/environmental standards, and obligation to future generations.

**Short-term disturbances** include: pandemics/changes in workforce, social unrest, changes in availability and/or cost of materials or parts, technology disruption, availability of investment capital, economic downturns/upturns, extreme climatic events, shifts in weather patterns, sudden changes in political landscape, changes in supply chain legislation, changes in business ownership, and shocks that change ethical stances.

**Long-term disturbances** include: changing demographics, globalization and future markets, scarcity of resources, mass customization, dynamic technology and innovation, climate change, global knowledge society, and the role of global non-profit and philanthropy organizations [11].

**Step Three:** ***'Develop an initial conceptual framework, identifying key drivers, including management and development options as well as state and utility variables and their interactions'*** [10].

An initial conceptual framework for the research was developed by the project team. This was partly based on data gathered during the STEEPLE analysis and partly on the Press-Pulse Dynamics framework from Collins et al. [12]. This framework sets disturbances in context, in relation to an ecosystem and the human systems that live within it; it defines a "press" as a long-term stressor, such as sea level rise, and a "pulse" as a discrete event that rapidly alters ecosystem function. While Collins et

[1] The UK's Engineering and Physical Sciences Research Council (www.epsrc.co.uk)

al.'s framework is designed to enable discussion of human-ecosystem interactions, we have applied it to the discussion of the environment in which manufacturing operates. Thus, we interpret presses as manufacturing mega-trends (taken from the Factories of the Future Roadmap [13]), and pulses as short-term risks to the city, its residents, and to economic activity (taken from national [14] and local risk registers [15]). The Pulse-Press Dynamics framework also uses the terms "structure" and "function", which are used in the field of ecology to differentiate between the core components of an ecosystem and the suite of processes that occur within the ecosystem [16]. We use these terms to distinguish the structural (e.g. infrastructure) elements of the manufacturing and economic/social systems from the functional ones.

Fig. 1 presents a first version of the RDM|RSC research framework. On the right, the local manufacturing template includes the structures that enable manufacturing, and the ongoing functions carried out by manufacturers. In the middle, the manufacturing "environment" incorporates the local biophysical environment and social/economic systems. Key parts of this manufacturing environment are assigned as structure or function. On the left, the key pulses and presses that have been identified so far are named.

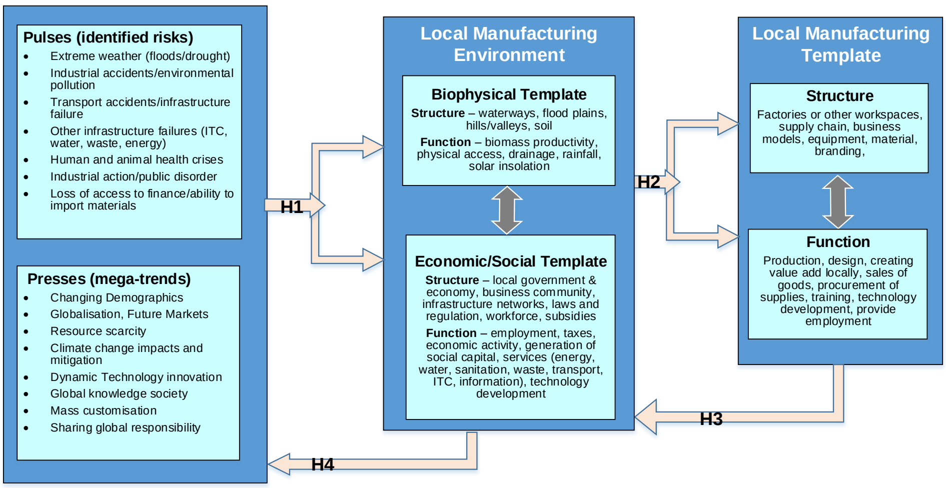


**Fig. 1.** Research Framework for Exploring the Impact of Disturbances on the City-Region and its Manufacturing Sectors

Four integrating hypotheses are represented as arrows in the diagram.

**H1:** Pulses and presses from inside the local environment (e.g. public disorder) or from outside (e.g. loss of access to finance) can affect both the structure of the environment and/or the functioning of the environment. The more resilient and sustainable the environment is, the more easily systems will be able to regain normal functionality after a pulse and/or continue to function under the pressure of various presses.

**H2:** The dynamics of structure and function within the manufacturing sector are dependent on and highly influenced by changes in the environment in which it operates, including the biophysical structure and functions, and the economic and social structure which provides essential services and infrastructure – such as the supply of materials and parts for different types of manufacturers. Some of this functionality, in economic terms, can be seen as adaptive *'collective agency*' [17].

**H3:** The activities of manufacturers – including creating jobs, designing new products and services, adding local value – and the structures developed to support manufacturing activity affect the local environment through adding to the tax base, creating social capital, toxic emission, creating demand for infrastructure, etc.

**H4:** The way the local environment is managed, the way that human activities are carried out, and the way that the local economy and society is managed can have an effect on the severity or likelihood of pulse events. For example, social unrest is more likely if there are chronic societal problems; infrastructure failures are more likely in an environment that is less economically resilient.

**Step Four:** ***'Workshop the initial conceptual framework and general scenarios with stakeholders'*** [10].

The framework presented in Fig. 1 was converted into a "strawman" Causal Loop Diagram (CLD) by the project team. CLDs are '*visual representations of the dynamic influences and inter-relationships that exist among a collection of variables*' [18]. CLDs can help by quickly capturing hypotheses about the causes of system dynamics, eliciting and capturing the mental models of individuals or teams about the system, and communicating important feedbacks [19].

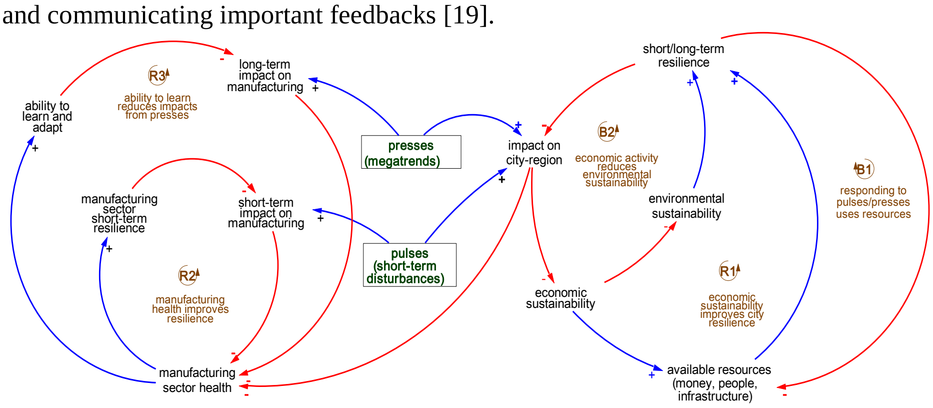


**Fig. 2.** "Strawman" Causal Loop Diagram representing theories about causal relationships between different types of resilience and sustainability, and the manufacturing sectors, as presented to Workshop Participants. (Positive causation is represented by blue arrows with a "+" sign, and negative causation is represented by red arrows with a "–" sign. Balancing (i.e. goal seeking) loops are named B1, B2 and reinforcing (i.e. growth) loops are named R1, R2, R3.)

The strawman CLD (Fig. 2) was presented to groups of participants in a workshop, with the intention to stimulate debate about the interrelationships between system elements, evaluate which elements might be missing (or superfluous), and think about what the role of RDM might be in future. Workshop participants were members of the project's network, from a variety of backgrounds including academia (e.g. economists, engineers, climate scientists), manufacturing, local government, and citizens.

Each of the workshop groups came up with a wide variety of additions and changes to the model, with some groups focusing on a particular manufacturing sector. There was lively discussion about the nature of resilience and sustainability in a region, the resilience of certain manufacturing sectors such as aerospace, industries that had once thrived in Bristol but failed to survive globalization, the potential role of new technologies such as Additive Layer Manufacturing, and more philosophical observations about the role of manufacturing in our society.

Several themes emerged during a general discussion with participants, including: The **future of work** and the quality of jobs: if new technologies create high levels of productivity in some industries and new skill requirements, how will employment polarization between those who have good jobs and those who have poor or no jobs at all be avoided? The cultural **distance between society and the physical realities of manufacturing**: manufacturing is increasingly done in the virtual design world, which limits our appreciation for physical limitations and materials – the key to sustainability and resilience. The relationship between pulses and presses: since people in general are poor at dealing with long term trends so **pulses are what comes to matter** to organizations and what they respond to. The desire to increase prosperity encourages the reinforcing of **"local for global"** innovation, and the desire to sustain manufacturing in the face of strong presses encourages **"local for local"** innovation. **Time is a critical factor** in the model; the model is dynamic and moving, not static, and has emergent properties. For example, as skills develop within certain industries, that will generate new, innovative businesses, possibly previously un-thought of.

**Further Work, Steps Five to Eleven:** The remaining seven steps in the IA process will be done during 2016 and will conclude with a distribution of the results to relevant stakeholders and user groups. This work will include: (i) researching what data exists regarding manufacturing in the region (e.g. physical production, material flows, and waste flows), and establishing suitable dimensions and time scales for mapping manufacturing and making in the region; and (ii) planning the development of a dynamic, systemic, and simulatable model (or set of models) that could represent the combined understanding from the workshop participants and findings from a wide range of reports and data analysis, and could be used to test different "what if" scenarios for RDM in the future.

## 4 Discussion

In terms of methodology, use of the IA approach has been valuable as a formal process for exploring a very wide-ranging and complex sustainable manufacturing issue. The research so far has found that causal loop diagramming is an appropriate method for starting to think about dynamic relationships between the key research issues at the societal level. Later steps in the IA will choose one or more formal systems modeling methodologies. System dynamics [19] would be suitable for creating insight into the interrelationships between the different resilience and sustainability characteristics of the system. Event-driven modeling could be added to a system dynamics model to represent pulses and presses (e.g. Schieretz and Grossler combined system dynamics with agent based modeling [20] to examine supply chain structures). Agent-based modeling could also be appropriate, since much of the potential for RDM is likely to be actualized by innovative businesses of different sizes and types.

In terms of findings, several apparent dichotomies and conundrums within the research agenda have already been identified, and these will be explored in more depth as we move forward with the IA steps. These issues include:

**Timing of organizational response:** Are cities and organizations likely to anticipate long-term changes (presses) or are they more likely to wait until there are short-term shocks (pulses) that impact their operations?

**Modeling physical flows**: Due to a lack of data, it may not be possible to model, even at a very high level, the flow of materials into and out of the region, or the amount of physical manufacturing that is being done. It may, however, be possible to understand these issues for a few companies and their practices through case studies.

**Divergent characteristics**: There are boundary issues with the four concepts of resilience and sustainability, as defined in Section 1. For example, is a company that stays in business resilient even if does so by sending production jobs overseas? Knowledge economy jobs could be considered preferable to production jobs since they provide economic gain with lower environmental impacts, but how do they affect the resilience of the region in terms of supplies of physical goods?

**Heterogeneity in manufacturing**: Ideally, we could consider the historical performance and future potential of a wide range of manufacturing entities in the region, in terms of size, sector, and technologies used - from a single person making musical instruments, for example, all the way up to a huge aerospace manufacturing plant – since they all may have potential for introducing RDM. Can this variety be included in a model in which elements are aggregated, and how would potential for RDM be limited by the type of manufacturing being done and materials used?

**Skills and jobs:** High-value RDM could contribute a great deal to economic sustainability, but what are the implications for lower-skilled workers? Unless the skills of the local workforce are updated to meet the demands of implementing RDM, it may not solve the persistent unemployment problem that has existed in some parts of the city since several large factories closed down

**Uncertainty about disturbances:** The size of uncertainty in terms of future presses and pulses is very large. This could be felt in changes to the nature of commerce, the nature of work, availability of materials, international logistics and trade, the role of technology in manufacturing, amongst many other changes. Will it be possible to even model a "what if" scenario that includes such levels of uncertainty? How much will the future look like the past?

**Location of impacts:** It's possible that whilst reshoring of jobs is one of the expected benefits, reshoring could re-import the environmental impacts associated with production that are now offshored. Is the city and the business community prepared to invest in minimizing these negative impacts?

**Making use of opportunities:** In addition to hazards, there could be many opportunities inherent in the range of future presses and pulses. What types of RDM can make the best use of them? What types of networks and social connections can be utilized to create appropriate responses in the local economy?

## 5 Conclusions

The research agenda for the RDM|RSC project presented a need for an approach that could explore the potential for re-distributed manufacturing at a societal level and link it to the issues of resilience and sustainability within a region. This requires viewing RDM as both dependent on regional sustainability and resilience, and influencing it.

The approach of Integrated Assessment was applied to help deal with the wide range of subjects and issues involved, and to investigate the dynamic complexity of systems. Research objectives, a stakeholder map, and a research framework were developed as part of the IA. The research framework makes use of concepts from ecology, naming disturbances as "pulses" or "presses", and conceptualizing the local biosphere and social/economic systems as making up the environment in which manufacturing is done.

A "strawman" causal loop diagram, representing a theory about the relationships between different types of sustainability and resilience and manufacturing, was presented to several groups of workshop participants. The workshop discussions revealed several apparent dichotomies and conundrums within the research agenda, which will be explored in more depth as the research continues. The approach so far has opened many "cans of worms" and it is anticipated that through the rest of the research project we will rely on our network of experts and manufacturers to be part of the modelling process and inform the research so that it remains relevant and useful to both the sustainable manufacturing community and research policy makers.

## 6 Acknowledgements

The RDM|RSC project is funded by the UK's Engineering and Physical Sciences Research Council, grant EP/M01777X/1. The authors would like to sincerely thank all of the participants in the RDM|RSC network for their time, knowledge and interest.

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